

RIFT PROCESSES AT VALLES MARINERIS, MARS: RATE DEPENDENT STRENGTH EVOLUTION VERSUS NECKING. F. Scott Anderson and Robert E. Grimm, Department of Geology, Arizona State University, Tempe, AZ 85287-1404 (Scott.A@asu.edu; see details at <http://violetta.la.asu.edu>, grimm@violetta.la.asu.edu).

Introduction. Three models of rift formation for Valles Marineris (VM) are being compared to understand the dominant physical processes involved in forming large troughs. Analytical models for extensional processes generally fall into two categories, those incorporating the evolution of lithospheric strength as a function of time [1] (our first model), and those based on necking instabilities [2,3] (the second model). We have applied both types of model to VM, comparing the lithospheric structure (crustal thickness and heat flow) predicted by each model necessary for the formation of the observed troughs. These models are compared to independent constraints on crustal thickness and heat flow obtained by refining previous gravity models [4] of the lithospheric structure at VM. The third rift model, still under development, uses finite element methods to avoid the numerous assumptions inherent in the analytic models, yet incorporates the physics of both.

Constraints from gravity and flexural modeling. Constraints on crustal and elastic lithospheric thickness are calculated from gravity models [4]. These results have been refined by, (1) achieving a better match between the gravity predicted from test lithospheric structures and observed gravity (Figure 1), (2) validating the results against a second gravity model, Mars50c [5], and (3) verifying the gravity data against original Viking Orbiter LOS data. The range of best fit crustal thickness is $H = 35\text{--}70$ km, with an elastic lithospheric thickness of $T_e < 22$ km, at the time the present trough morphology was established. The lithospheric structure corresponding to these parameters has undergone strain of 9-15% [4].

McNutt [6] recognized that heat flux (q) is related to elastic lithospheric thickness through lithospheric structure and curvature. Using this relationship, T_e calculated from the refined gravity model has been converted to q . Lithospheric structure is known from the gravity model, and curvature is approximated as the maximum second derivative of topography averaged over representative cross sections through VM. This value is justified by the extreme thinning, bending, and plastic flow required to generate compensated topography for VM. The results indicate that heat flow is $q > 30 \text{ mW/m}^2$ at the time the topography was established. *Schultz and Senske* [7] have argued that the appropriate curvature for VM can be measured across the topographic high on which VM is centered, interpreting the high as flexural uplift. However, support of the large horizontal extent (> 1000 km) of the curvature requires an anomalously large T_e (~ 185

km [8]), which is inconsistent with the gravity data. Terrestrial studies of the East African rift valley [9] demonstrate similar profiles that are not interpreted as flexural uplift, but instead as regional crustal thickening. This explanation for the high topography at VM would not only be consistent with the gravity data, but also suggests a mechanism for the localization of rifting along the topographic high. As shown in the gravity model [4], the combination of flexural and isostatic support of the crustal bulge would result in an increased crustal thickness beneath VM (up to 90 km) creating a much weaker region of lithosphere in which to localize extension.

Strength evolution model. Results from the strength evolution model have been previously reported [4, 11]. These results showed the gravity constraints based on a lithospheric strength approximation method [4]. Here we show the exact values of q (Figure 2) as calculated from the full lithospheric structure, as well as the previous results (dashed lines). In conjunction with the gravity results, we find that wide rifting is favored over narrow rifting. If we rule out core complex formation [11], $H = 35\text{--}80$ km, and $q = 30\text{--}80 \text{ mW/m}^2$.

Necking model. The necking model calculates the wavelengths of maximum deformation in a one layer viscous medium under extension [2]. Due to the single layer nature of this simple model, it can only be applied to lithospheres dominated by the crust or the mantle. Fourier analysis of VM indicates that the wavelength of deformation is 250 ± 50 km, with a secondary wavelength of 100 km and 20% of the amplitude. As with previous models, rheology is assumed to be a diabase crust [12] or a dunite mantle [13], and extension rate $v = 0.01$ cm/yr. Results are shown in Figure 3. Lithospheres dominated by crustal rheologies are depicted on the right of the decoupled zone (black arc), and mantle rheologies are shown on the left. None of the observed deformation wavelengths lie within the gravity constraints. These results suggest that for a necking model to work, it must have 2 rheologic layers separated by a weak layer. We define a decoupled zone as a change in strength of more than 20% and an overall strength < 200 MPa. Multiple layer models typically result in multiple wavelengths of deformation [3]. If the weak 100 km wavelength represents a second wavelength of deformation, we estimate that deformation is occurring in the decoupled zone with $H = 35\text{--}50$ km, and $q = 35\text{--}$

40 mW/m². We will rigorously calculate H and q with a third method (see Finite Element Model, below).

Model comparison. The results of the strength evolution and necking models indicate that the physics of strength evolution agrees with the predictions of lithospheric structure from gravity, however, a single layer model of necking cannot produce the heat flow predicted by gravity. A multi-layer necking model may produce results in the decoupled zone consistent with the gravity models. The heat flow of $q > 30$ mW/m² from the gravity model is only marginally consistent with the necking $q < 40$ mW/m², whereas the strength evolution model provides a more consistent range of $q=30-80$ mW/m².

Both of the analytic models contain assumptions: strength evolution models are not fully two dimensional, and necking models don't address evolution of the geotherm with time and finite extension. The best rifting model, currently being tested, incorporates the physics of both strength evolution and necking in a single model.

Finite element model. ANSYS finite element (FE) models in progress will allow us to incorporate the physics of brittle sliding, power law creep, isostasy, and evolution of the geotherm with time in a 2D model. Using FE methods we can calculate both rift morphology under large strain (strength evolution and necking) and the dominant wavelengths of deformation for infinitesimal strain for multiple layers (necking), without the problematic assumptions listed above, yielding more robust calculations of H and q.

References. [1] Buck, W.R. (1991) *JGR* 96, 20161. [2] Fletcher, R.C. and B. Hallet (1983) *JGR* 88, 7457. [3] Zuber, M.T. et al. (1986) *JGR* 91, 4826. [4] Anderson, F.S. and R.E. Grimm (1995), *LPSC XXVI*, 39-40. [5] Konopliv, A.S. and W.L. Sjogren (1995), The JPL Mars Gravity Field, Mars50c, Based Upon Viking and Mariner 9 Doppler Tracking Data, JPL Publication 95-5, Pasadena. [6] McNutt, M.K. (1984) *JGR* 89, 11180. [7] Schultz, R.A. and R.A. Senske (1995), *LPSC XXVI*, 1253-1254. [8] Turcotte D.L. and Schubert G. (1982) *Geodynamics*, John Wiley and Sons, New York. [9] Ebinger et al. (1989) *JGR* 94, 2883. [10] Solomon, S.C. and J.W. Head (1990) *JGR* 95, 11073. [11] Anderson, F.S. and R.E. Grimm (1994), *LPSC XXV*, 29-30. [12] Caristan, Y. (1982) *JGR* 87, 6781. [13] Chopra, P. and M. Paterson (1981) *Tectonophysics* 78, 543.

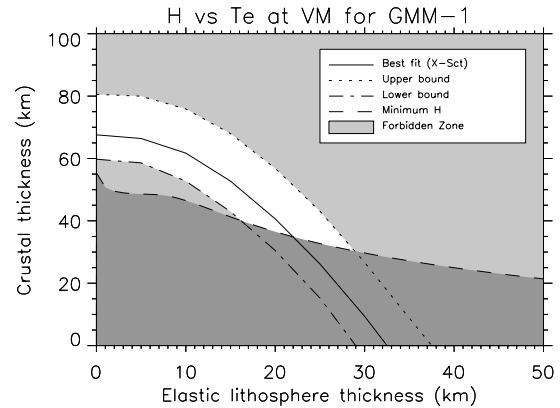


Figure 1: Refined H vs Te for GMM-1.

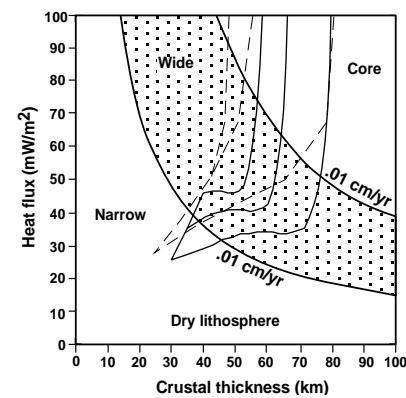


Figure 2: Strength evolution model with refined gravity constraints. The center line is the best fit, rightmost is the upper gravity bound, leftmost the lower gravity bound. The previous gravity results are shown as dashed lines.

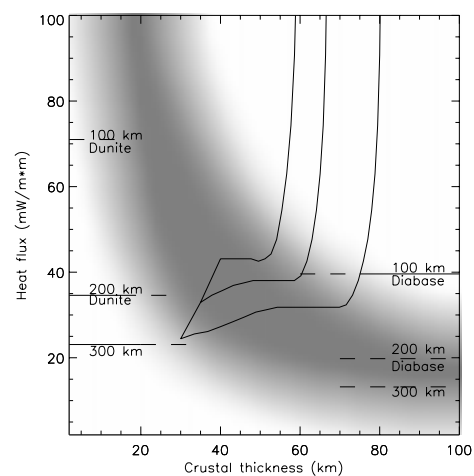


Figure 3: Necking model with refined gravity constraints. The numbers on the graph are deformation 1 and dominant rheology. Hence, values on the left represent a strong mantle, and values on the right a strong crust.